Science and Technology Indonesia
e-ISSN:2580-4391 *p*-ISSN:2580-4405
Vol. 9, No. 4, October 2024

Research Paper

Relativity and the Magnitude of Velocities

Musa Ajeti[1], Valbona Berisha[2]*, Shukri Klinaku[3]

[1]*Faculty of Applied Sciences, University of Gjilan, Gjilan, 60000, Kosova*
[2]*Department of Education, University of Prishtina, Prishtina, 10000, Kosova*
[3]*Department of Physics, University of Prishtina, Prishtina, 10000, Kosova*
***Corresponding author**: valbona.berisha@uni-pr.edu

Abstract
In modern physics, relativity is primarily understood through the framework of Einstein's theory. According to the special theory of relativity (STR), Galilean relativity serves as a very accurate approximation at low velocities, where 'relativistic effects' can be neglected. However, at high velocities, these effects become significant and are accurately described by STR. This paper challenges this understanding, arguing that the opposite is true. In Galilean relativity, the relativity of time is substantial and cannot be ignored. Thus, relative time is more negligible in STR than in Galilean relativity. By comparing Galilean relativity and STR through physical, mathematical, and specific examples, two conclusions are drawn: first, the current categorization of relativity theories based on velocity magnitude is artificial and inaccurate; second, the relativity of time can be ignored in special relativity, while it remains significant and cannot be overlooked in Galilean relativity.

Keywords
Galilean Relativity, Special Relativity, Velocity of Light

Received: 29 March 2024, Accepted: 17 June 2024
https://doi.org/10.26554/sti.2024.9.4.790-797

1. INTRODUCTION

In the realm of special theory of relativity (STR), the spatial coordinates and time of an event in two frames of reference, which are in relative motion with a velocity v, are connected through the Lorentz transformation (LT) (Equation (1)),

$$\begin{aligned} x' &= \frac{x - vt}{\sqrt{1-\frac{v^2}{c^2}}} \\ y' &= y \\ z' &= z \\ t' &= \frac{t - \frac{vx}{c^2}}{\sqrt{1-\frac{v^2}{c^2}}} \end{aligned} \tag{1}$$

where x, y, z, t are the spatial coordinates and time in frame of reference S, and x', y', z', t' are the spatial coordinates and time in frame of reference S'; and c is the velocity of light. According to STR, LT is necessary for the identification of "relativistic effects", two of which are the main ones: length contraction and time dilation. According to STR, for small $v(v << c)$, these effects become negligible in Galilean relativity due to the small value of the ratio v/c. While for sufficiently large v, the relativistic effects are identifiable, and LT becomes necessary for accurate representation of situation (Alstein et al., 2021; Einstein and Infeld, 1938; Landau and Lifshitz, 1987; Born, 2001; Lämmerzahl, 2005; O'Donnell, 2015; Feynman, 1977; Halliday et al., 2022; Serway and Jr., 2014; Günther and Müller, 2019). As Einstein and Infeld (1938) wrote, "*The old mechanics is valid for small velocities and forms the limiting case of the new one*". Landau and Lifshitz (1987) wrote: "*Large value of the velocity of light explains the fact that in practice classical mechanics appears to be sufficiently accurate in most cases. The velocities with which we have occasions to deal are usually so small compared with the velocity of light that the assumption that the latter is infinite does not materially affect the accuracy of the results.*". Born (2001) wrote: "*For if v/c can be neglected in comparison with 1, we get from Lorentz transformation This helps us to understand how, on account of the small value that v/c has in most practical cases, Galilean and Newtonian mechanics satisfied all requirements for some centuries.*"

$$\begin{aligned} x' &= x - vt \\ y' &= y \\ z' &= z \\ t' &= t \end{aligned} \tag{2}$$

According to modern physics, system of Equation (2) represents GT. It should be noted that the current GT is a 'Made in Modern Physics' product (Browne, 2020; Larmor, 1900; Laue, 1911), derived by neglecting the v/c ratio from LT (Equation (1)). In other words, the current GT is not an analytical derivation of Galileo-Newtonian mechanics. Two important questions will be reviewed in this paper regarding this ratio: Why is the speed of light present in this ratio, and does such a ratio have a place in GT? The answers to these two questions will be derived with physical, and mathematical explanations and concrete examples. We will compare the influence of the velocity magnitude in Galilean relativity and STR. From this comparison, with concrete examples, it will become clear that the current categorization of relativity theories based on the magnitude of velocity is artificial and incorrect. Furthermore, this paper shows that contrary to what modern physics suggests, the relativity of time cannot be neglected in Galilean relativity. In other words, the relativity of time is always present and easily noticeable in our daily lives; so noticeable that it cannot be neglected.

2. PRINCIPLE OF RELATIVITY FOR VELOCITIES

The starting point of STR is the special nature of the speed of light (Bhadra et al., 2023; Landau and Lifshitz, 1987; Lämmerzahl, 2005; Welters et al., 2014; Kamphorst et al., 2019). According to STR this special nature of the speed of light is direct result of its fundamental postulates. These postulates align with reality, and we will endeavour to demonstrate that they do not confer any special status to light. The special status of the speed of light in STR is derived from the misinterpretation and misapplication of the principle of relativity. Light is extraordinary to us, but ordinary to the laws of physics.

2.1 Principle of Relativity: the Absence of a Privileged Velocity

The principle of relativity asserts that there is no privileged frame of reference in the study of motion. As we know, any object can be regarded as a frame of reference. Consequently, there is no privileged body in relative motion. Therefore, based on these premises, it follows that neither photons nor light wavefronts hold a privileged status. In other words, since we can associate a frame of reference with a photon or a light wavefront, it implies that light itself is not privileged. Ultimately, within the framework of relativity, there exists no privileged velocity, and this includes the velocity of light.

2.2 The Meaning of the Constancy of the Velocity of Light

Is it possible for the velocity of light to remain constant in all inertial reference frames without being privileged over other speeds? To answer this question, let us examine a few examples and deduce our conclusion. We will examine the Doppler effect (Figure 1) as it represents the clearest example of compound relative motion (Klinaku, 2024; Klinaku, 2021). To illustrate this, we can remove the circles representing the propagation of the wavefronts in Figure 1, and we then observe that we are dealing with a typical case of compound relative motion. Since all motions are relative; we have simple relative motion, in which one body moves relative to another; and "compound relative motion", where two bodies move relative to a third one. The Doppler effect and the motions for which Equations (1) and (2) are derived are typically compound relative motion. Each observer stationed at points P, P_1, P_2, P_3, P_4 records a distinct frequency that is specific to their respective location and differs from the frequency emitted by the source (Figure 1a and 1b). It is evident that the speed of the wavefront (c) and the speed of the wave source (v) remain constant. The only velocity that changes and influences the observed frequency is the relative velocity (the relative velocity between the wavefront and the source). In Figure 1a, the observer at point P experiences a relative velocity u, while the observer at P_1 experiences a relative velocity u_1, and so on. It is important to note that we are discussing the constancy of the velocity of light. In Figure 1a, the magnitude of the velocity c remains consistently constant in all directions. The fact that the relative velocity (combination of c and v) changes should not be mistaken for a change in the constant velocity of light and the velocity of its source. Both velocities remain constant, but the relative velocity formed by their combination varies due to the changing angle between them, corresponding to the shifting position of the observer. Therefore, the physical quantity that governs the change in the observed frequency is precisely the relative velocity (u) between velocities c and v. It is worth noting that Figure 1a can be presented differently, conforming to the preferred representation in modern physics. Instead of using the relative velocity, we can express it as the velocity of light (c) and visually fulfill the "requirement" that the velocity of light remains constant in any reference system (Figure 1b). However, in this case, since we denote c instead of u, we must also change the time variable from t to t', so that the new product ct' (Figure 1b) equals ut (Figure 1a):

$$ut = ct' \tag{3}$$

Certainly, this change in notation does not alter the observed results; but it offers a valuable opportunity to go deeper into the problem. The physical interpretation of Equation (3) is as follows: the signal emitted by the moving source travels along the path $O'P$ towards the observer. We can calculate this path by multiplying the relative velocity of the signal ($u = c - v$) by the time of the event. Alternatively, we can calculate it by multiplying the velocity of the signal (c) by the relative time (t'). The relative time, denoted as t', differs from the time t due to the velocity v. In other words, Equation (3) demonstrates that the contribution of the velocity v can be accounted for within the relative velocity u (on the left side of the equation) or within the relative time t' (on the right side of the equation). This equation encapsulates the Doppler effect and Galilean relativity. Moreover, it serves as a key to understanding relativity. As mentioned, the velocity u represents the relative velocity composed of the components c and v, which can be determined using the law of cosines (Klinaku, 2021; Berisha and Klinaku, 2018:

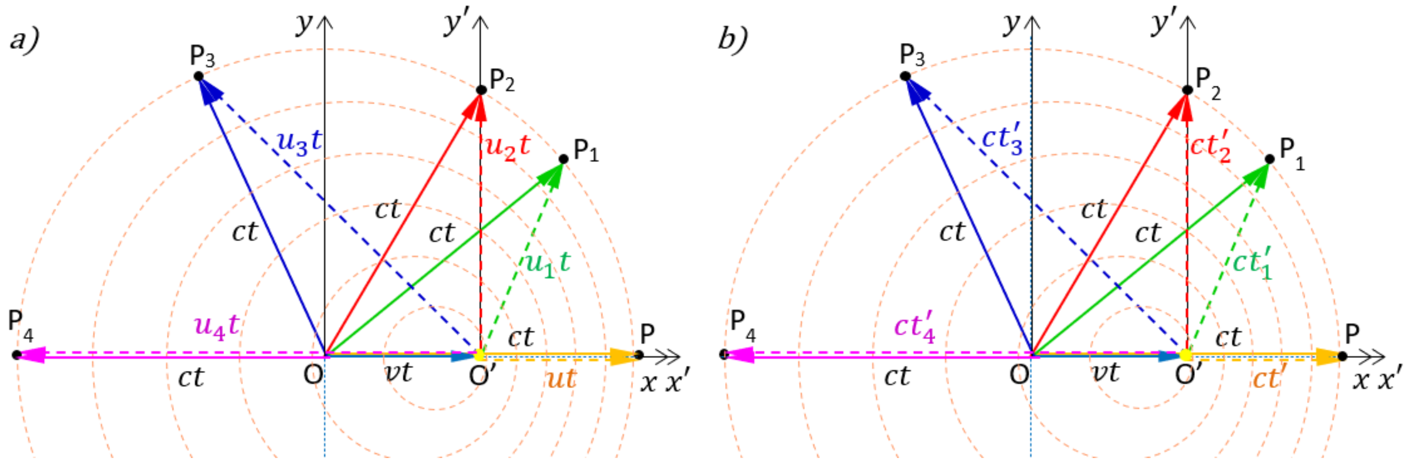

Figure 1. Relativity Expressed with the Doppler effect

$$u = c\sqrt{1 - \frac{v^2}{c^2}sin^2\vartheta} + vcos\vartheta \tag{4}$$

where ϑ represents the angle between the direction of velocity v and the observer's line of sight towards the wave source. Equation (4) is derived from Figure 1a. Similarly, by performing the same analysis on Figure 1b, we obtain the relative time t' (Klinaku, 2021):

$$t' = t\left(\sqrt{1 - \frac{v^2}{c^2}sin^2\vartheta} + \frac{v}{c}cos\vartheta\right) \tag{5}$$

which corresponds to the 'time Doppler effect' (5). Velocity u in Equation (4) is not the velocity of light. Modern physics refers to relative velocity u as the velocity of light, but this interpretation is incorrect. Modern physics should distance itself from this long-standing error. To illustrate this, let us make a comparison. If modern physics considers Equation (4) as the velocity of light, then by the same logic, it could also be regarded as the velocity of the light source v. This is because both c and v are constituents of u. Treating the relative velocity as the velocity of light is akin to treating the relative velocity v_{AB} as v_A, despite knowing that $v_{AB} = v_A + v_B$. So, why would we call it v_A and not v_B? In our case, the fact that the magnitude of velocity c is much greater than that of velocity v does not render the latter non-existent. In conclusion, the change of u doesn't mean the change of c.

Let us proceed with another comparison. Just as the 'second postulate' states that the velocity of light is independent of the velocity of the source, the "postulate" of relativity implies the equivalent statement that the velocity of the source is not influenced by the velocity of the light it emits. Modern physics needs to acknowledge the truth, the value of velocity v as part of the relative velocity is essential for determining the frequency change. The frequency change is precisely determined by the velocity u (Equation 4). By employing Equations (3) and (4) and utilizing the established relationships between frequency and time $t' = 1/f'$, wavelength and frequency $\lambda' = 1/f'$, and wavelength and distance $n\lambda' = r'$, the following equations can be derived (Klinaku, 2024):

$$\frac{1}{f'} = \frac{1}{f}\left(\sqrt{1 - \frac{v^2}{c^2}sin^2\vartheta} + \frac{v}{c}cos\vartheta\right) \tag{6}$$

$$\lambda' = \lambda\left(\sqrt{1 - \frac{v^2}{c^2}sin^2\vartheta} + \frac{v}{c}cos\vartheta\right) \tag{7}$$

$$r' = r\sqrt{1 - \frac{v^2}{c^2}sin^2\vartheta} + vtcos\vartheta \tag{8}$$

These equations represent: the Doppler effect expressed in terms of frequencies (Equation (6)), the Doppler effect expressed in terms of wavelengths (Equation (7)), and the Galilean transformation in polar coordinates (Equation (8)), which can also be called the Doppler effect expressed in terms of lengths (Klinaku, 2021). By substituting $\vartheta = 0°$, $\vartheta = 180°$ and $\vartheta = 90°$ into these equations, we obtain the equations for specific cases that correspond to the longitudinal Doppler effect, the transverse Doppler effect, and the Galilean transformation in Cartesian coordinates. In the same way, when angle ϑ takes these particular values in Equation (4), we obtain the well-known expressions for the relative velocity:

$$u = c + v \tag{9}$$

$$u = c - v \tag{10}$$

$$u = \sqrt{c^2 - v^2} \tag{11}$$

which in the Doppler effect and relativity equations must be treated as the relative velocity between the velocity of light and the velocity of its source because they are relative velocity between the velocity of light and the velocity of its source.

Equations (9) and (10) represent longitudinal case, while Equation (11) represents transversal case. The principle of relativity not only demonstrates that light maintains the constant speed in all reference systems but also leads to two additional conclusions. Firstly, light is extraordinary for us as observers, but it is ordinary for the laws of physics since it participates in relative velocities like any other velocity. Secondly, the 'postulate' regarding the velocity of light is valid and applicable to any velocity. This means that any velocity, that is constant in one frame of reference, will also be constant in all other frames of reference that are inertial relative to the first.

2.3 The Postulates of STR Do Not Claim Velocity of Light Is the Limit Velocity for All Velocities

According to the principle of relativity, "*all the laws of nature are identical in all inertial systems of reference. In other words, the equations expressing the laws of nature are invariant with respect to transformations of coordinates and time from one system of reference to another. This means that the equation describing any law of nature, when written in terms of coordinates and time in different inertial reference systems, has one and the same form. (...) In actuality, if any change takes place in one of the interacting bodies, it will influence the other bodies only after the lapse of certain interval of time. It is only after this time interval that processes caused by the initial change begin to take place in the second body. Dividing the distance between the two bodies by this time interval, we obtain the velocity of propagation of the interaction. We note that this velocity should, strictly speaking, be called the maximum velocity of propagation of interaction. (...) It is clear that, existence of a maximum velocity of propagation of interaction implies at the same time, that motions of bodies with greater velocity than this are in general impossible. (...) From the principle of relativity, it follows in particular that the velocity of propagation of interactions is the same in all inertial systems of reference. Thus, the velocity of propagation of interactions is a universal constant. This constant velocity is also the velocity of light in empty space*" (Landau and Lifshitz, 1987). The idea that the speed of light is the limiting speed in the Universe, as presented by Landau and Lifshitz (1987), is based on the principle of relativity. However, this position can be challenged based on the following observations: (i) The principle of relativity deals with the laws that connect physical quantities, not with the specific numerical values of those quantities. It states that the laws of physics are the same in all inertial reference frames. It does not inherently imply a limit on the velocity of objects. (ii) A body A, which moves according to the principle of relativity has its velocity, which is not affected by the velocity of other bodies in that motion; but, the velocity of body A, together with the velocity of body B in the same motion – constitute a relative velocity v_{AB}. This velocity always differs from the velocity of body A and from the velocity of body B. In conclusion, the velocity of body A can be the limit velocity in a single reference system, but not in all reference systems, because at least the relative velocity v_{AB} can exceed it. Can the limit velocity come from the 'postulate' of the velocity of light? Below we bring various formulations of this postulate. Born (2001): "*Experience shows that the velocity of light, regardless of the velocity of the observer, always has a constant value c*". Feynman (1977): "*... if the source of disturbance is moving, the emitted light goes through space at the same speed c. This is analogous to the case of sound, the speed of sound waves being likewise independent of the motion of the source*". Feynman is one of the few physicists who mention the fact that sound has the same property as light in Einstein's postulate. Lämmerzahl (2005): "*The propagation of light is a universal and unique phenomenon (the velocity does not depend on the velocity of the source)*". From these definitions and from all the others (Feynman, 1977; Halliday et al., 2022; Serway and Jr., 2014; Günther and Müller, 2019; Welters et al., 2014), it seems that they are all about the independence of the velocity of light from the velocity of its source, or about the constancy of the velocity of light. And none of them refer to the relative velocity between light and its source/ observer or the velocity of light as a limit velocity; none of them asserts that relative velocity must be equal to the velocity of light. Thus, the 'postulate' of the velocity of light is a true assertion, however it does not produce any velocity as limit for other velocities.

The idea that the velocity of light is the velocity limit in the Universe originated from the velocity addition formula (VAF) in STR. However, this formula is not fundamental and does not directly derive from the principles of relativity. Furthermore, the derivation and functionality of the velocity addition formula in STR have been questioned in various ways. One point of concern regarding the velocity addition formula is that if we solve it for the velocity of light c,

$$c^2 = \frac{uu'v}{u' + v - u'} \tag{12}$$

we encounter certain inconsistency. Indeed, it does not make sense for the velocity of light, which is considered to be a natural constant and the velocity limit in the Universe, to "become" zero (or at best, an undefined value) when the velocity v or the relative velocity u' is zero (12).

2.4 Principle of Relativity Is Unique for All Physics

Since light follows the same principles of motion as other objects, and its velocity is not a limiting factor in terms of relativity, and since wave equations are invariant regardless of the type of wave (Klinaku, 2022; Berisha and Klinaku, 2023), we can conclude that the principle of relativity is universally applicable to all laws of physics. In other words, there is not one principle of relativity for Galilean relativity, and another for STR; but there is a unique one for both theories. Even Einstein who today has full credit as the author of STR has said this in the introduction of general theory of relativity.

3. WHY IS THE VELOCITY OF LIGHT PART OF LORENTZ TRANSFORMATION?

As we know, the velocity of light c is always part of LT (1), regardless of whether we are dealing with the motion of light or not. Why is the velocity of light part of LT? In fact, a more appropriate question would be: Why should LT, derived for light, be applied to solving problems involving the motion of other objects? When explaining Galilean relativity, we consider the motion of a body with any velocity (such as the velocity u' relative to the $x'O'y'$ system). However, when discussing STR, we always consider a light signal with velocity c. It is often concluded that LT derived in STR, specifically for light, applies to all bodies at any velocity. To address this anomaly, some authors have attempted to define a 'relativity without light' that applies to all bodies, including light. Their aim is to obtain a kind of 'general LT' without relying on the velocity of light. Although this idea has some merit, their approaches have not yielded any alternative explanations beyond substituting the inverse of the square of velocity c with a 'constant value n' (Ignatowski, 1910; Anker and Ziegler, 2020). Among the various paths taken, Born's approach for deriving LT (Born, 2001; Berisha and Klinaku, 2017) is the simplest. Born explicitly uses the 'equations of the constant speed of light' in his derivation process,

$$\left.\begin{aligned} c &= \frac{x}{t} \\ c &= \frac{x'}{t'} \end{aligned}\right\} \tag{13}$$

After considering the physical behavior of light in two reference systems, Born arrives at the following system of equations:

$$\left.\begin{aligned} \alpha x' &= x - vt \\ \alpha x &= x' - vt' \end{aligned}\right\} \tag{14}$$

and by substituting Equation (13) into Equation (14), he obtains LT (Equation 1). Equation (14), α represents the "proportionality factor", and t' denotes the time in reference system $x'O'y'$ (Born, 2001).

Now we need to demonstrate that Equation (13) are also applicable to any velocity in a combined relative motion; and this confirms the existence of a "general LT". Therefore, we must establish the validity of the following Equation (15):

$$\left.\begin{aligned} u &= \frac{x}{t} \\ u &= \frac{x'}{t'} \end{aligned}\right\} \tag{15}$$

These equations are valid for the motion of two reference systems with a constant velocity v relative to each other, as well as for the motion of a body relative to the reference system $x'Oy'$ with a velocity u'. Here, u represents the velocity of the same body relative to the reference system xOy (as shown in Figure 2a).

In Figure 2a, we observe that the body P traverses the path x with a velocity u in time t. This gives us the first equation of Equation (15). However, when considering the same body relative to the origin O', we find that it traverses the path x' with the velocity u'. Remarkably, if we calculate the time it takes for the body to traverse this path x' with the velocity u, we find that it takes a shorter time than t (often denoted as t'). Consequently, we obtain the second equation of Equation (15). A graphical representation of this compound relative motion (Figure 2b) also provides a straightforward and clear derivation of Equation (15). The first equation arises from triangle OPD, while the second equation arises from triangle BCD. The validity of the system of Equation (15) can also be proved using the Doppler effect of all kinds of waves. By substituting Equation (15) into Equation (14), we arrive at the "general LT".

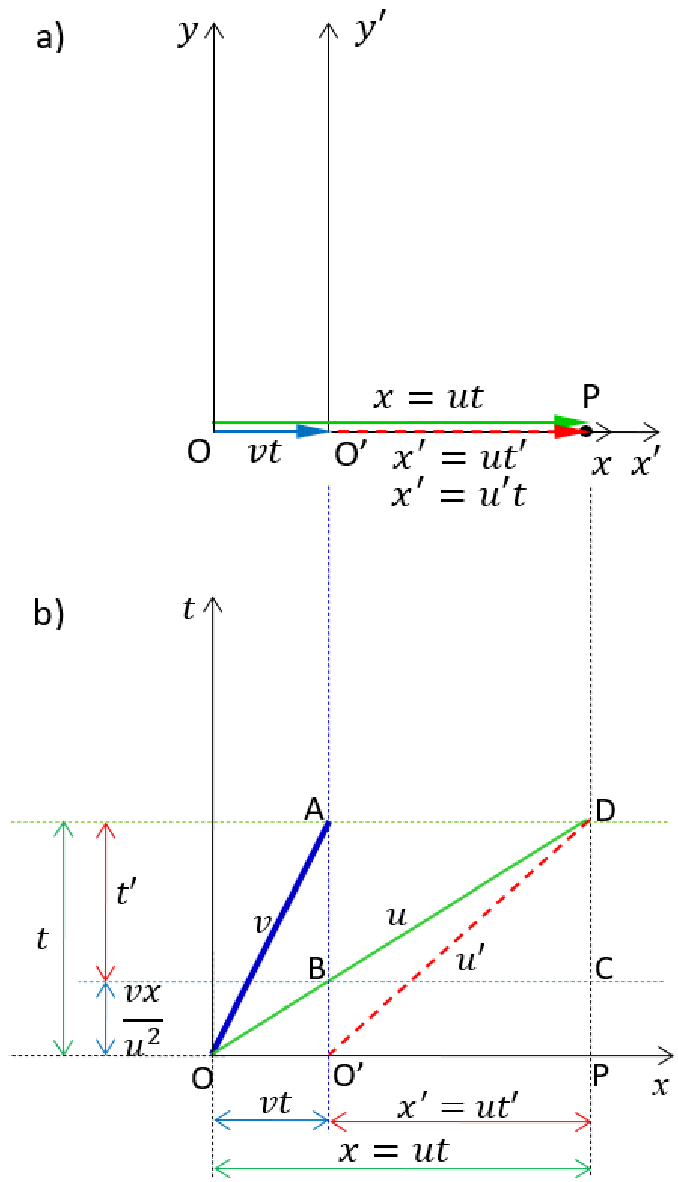

Figure 2. Relative Motion (a) and Its Space-Time Diagram (b) (Klinaku, 2022)

$$
\begin{aligned}
x' &= \frac{x - vt}{\sqrt{1 - \frac{v^2}{u^2}}} \\
y' &= y \\
z' &= z \\
t' &= \frac{t - \frac{vx}{u^2}}{\sqrt{1 - \frac{v^2}{u^2}}}
\end{aligned} \tag{16}
$$

Therefore, Equation (16) represent the 'general LT', which are derived without relying on the speed of light. They encompass the transformations of spatial coordinates and time for all velocities. This approach to deriving Equation (16) demonstrates that the principle of relativity alone is adequate for obtaining the equations of transformation. However, for Equation (16) to hold true, we need to examine how Equation (14) are derived.

4. RELATIVITY OF TIME IN GALILEAN RELATIVITY CANNOT BE DISREGARDED

The presence of the parameter α and time t' in Equation (14) raises the need for reconsideration of their physical basis. Why is Born "forced" to convert the time t to the time t'? He is "forced" to do so in order to satisfy the requirement of the principle of relativity, which implies that these Equation (14) should hold in their implicit form,

$$
\left.\begin{aligned}
x' &= f(x, z, y, t) \\
x &= f(x', y', z', t')
\end{aligned}\right\} \tag{17}
$$

However, the explicit form of Equation (17) should not be achieved through imputation but through the transformation of one equation into another and vice versa. This can be done clearly, simply, and without any convoluted assumptions as follows. From Figures 1 and 2, we obtain the indisputable Galilean transformation for the x coordinate, which is $x' = x - vt$. From this, we can write:

$$
\left.\begin{aligned}
x' &= x - vt \\
x &= x' + vt
\end{aligned}\right\} \tag{18}
$$

Equation (18) aim to represent the explicit form of Equation (17), but the time t is still present in both Equation (18). Through some transformations, we can make these equations fully satisfy even the requirement such that the quantities in system xOy be represented by the quantities in the system $x'O'y'$ (Figure 1b). To achieve this, we can use the equations that readily emerge from Figure 1b,

$$
\left.\begin{aligned}
t &= \frac{x}{u} \\
t &= \frac{x'}{u'}
\end{aligned}\right\} \tag{19}
$$

Using Equation (19) we eliminate the time t from Equation (18), so we obtain the following Equation (20):

$$
\left.\begin{aligned}
x' &= x(1 - \frac{v}{u}) \\
x &= x'(1 + \frac{v}{u'})
\end{aligned}\right\} \tag{20}
$$

Equation (20) represent the transformation of the x coordinate in both systems. The time transformation equations can be obtained by substituting the expressions for x and x' from Equation (15) in Equation (20). This will give us the desired transformations, as follows:

$$
\left.\begin{aligned}
t' &= t(1 - \frac{v}{u}) \\
t &= t'(1 + \frac{v}{u'})
\end{aligned}\right\} \tag{21}
$$

By rearranging Equations (20) and (21), we can obtain the transformations for the spatial coordinates and time as follows:

$$
\left.\begin{aligned}
x' &= x(1 - \frac{v}{u}) \\
t' &= t(1 - \frac{v}{u})
\end{aligned}\right\} \tag{22}
$$

and

$$
\left.\begin{aligned}
x &= x'(1 + \frac{v}{u'}) \\
t &= t'(1 + \frac{v}{u'})
\end{aligned}\right\} \tag{23}
$$

Equations (22) and (23) provide the explicit form of Equation (17). They represent the Galilean Transformation (GT) for the spatial coordinates and time in the context of Figure 2 (with the understanding that $y = y'$). As this transformation differs from the current GT (Equation 2), the new transformation given by Equations (22) and (23) can be referred to as the Transformed GT (TGT) (Klinaku, 2022; Berisha and Klinaku, 2023; Klinaku, 2024). TGT from its form presented in Equation (22), can be easily transformed into:

$$
\left.\begin{aligned}
x' &= x - vt \\
t' &= t - \frac{vx}{u^2}
\end{aligned}\right\} \tag{24}
$$

From TGT in the form (Equation 24), the difference between TGT and the current GT (Equation 2) becomes clearer. It is evident that the difference lies in the second term of the time equation. Thus, according to TGT, time is relative even within Galilean relativity. On the other side, the differences between TGT (Equation 24) and LT (Equation 1) are more extensive. Let us highlight the three main differences that are immediately noticeable. The first difference is that LT incorporates the Lorentz factor even in cases of longitudinal motion, whereas TGT (Equation 24) does not include this factor when the motion is longitudinal, as depicted in Figure 2 (TGT incorporates the Lorentz factor in specific cases where the velocities in the compound relative motion close a 90° angle (Klinaku, 2021; Berisha and Klinaku, 2018)). The second difference is that LT includes the speed of light c, even in cases of compound relative motion where the velocity of light is not involved (Figure 2). While TGT includes the speed of light c only when this velocity is part of the compound relative motion, as demonstrated in Equations (3-11) for the motion shown in Figure 1. The third difference, which is also the central focus of this paper, pertains to the distinction between times t and t' for the same event according to LT and TGT, respectively. The distinction between times t and t', according to LT and TGT, which will be in favour of TGT, can be easily demonstrated experimentally.

5. EXPERIMENTAL SECTION

We will provide only an overview of the experiment and the expected results, since the experiment is simple to conduct. The relativity of time in a compound relative motion is characterized by the difference between time t and t' within that motion. Now, let's compare these two times for an event calculated using LT and TGT. Let's consider the scenario where a wagon and a cyclist inside this wagon leave the station simultaneously and travel in the same direction. Both the wagon and the cyclist have a velocity of $v = 2.77778\ m/s$. We will determine how far the cyclist has travelled from the station (x =?) after a time $t = 1$ s, and in order to find the corresponding time t', after the cyclist has passed the path x. So, our task is to find what is t', which corresponds to time $t = 1\ s$, when $v = u' = 2.77778\ m/s$.

First, let us find the solutions by means of TGT. Using TGT (Equation 24), we can find the solution. In fact, the time t' can be determined without calculating the path x. By using the second equation of the system of Equation (23), we find that $t' = 0.5$ s. To find the time t' using the time equation of TGT (Equation 24), we need to find the path x and the velocity u. From the first equation of TGT (24), we find that $x = 5.55556\ m$, and the velocity u is also $5.55556\ m/s$. Substituting these values into TGT for time (Equation 24), we obtain $t' = 0.5\ s$.

Now, let's find the t' using LT. Without having to calculate, we can conclude that difference between times t and t' is so small that even the most accurate clock cannot detect it. The difference is less than $0.00000000000000001\ s$.

6. RESULTS AND DISCUSSION

First, we'll examine the equations and then consider concrete values for the physical quantities involved in the motion. When comparing the equations, we observe that the difference between times t and t' according to TGT (Equation 22) is determined by the term v/u (as seen in the second equation of Equation 22). This indicates that the difference between the event time t and the relative time t' would be insignificant only if u is much larger than v. However, when v and u have comparable magnitudes, the difference between t and t' becomes significant and cannot be neglected. On the other hand, according to LT (1), in the case where v represents the velocity of the wagon, the difference between time t and t' can be easily neglected because the terms vx/c^2 and v^2/c^2 are very small (Nolting, 2017; Born, 2001; Griffiths, 2024; Landau and Lifshitz, 1987). Therefore, according to LT, the difference between t and t' depends solely on the difference between v and c (since the velocity u does not appear explicitly in the equation). This implies that the difference between the event time t and the relative time t' according to TGT is significantly larger than the difference between these two times according to LT. The comparison underscores the notable distinction in the treatment of time between the two frameworks. In modern physics, it is stated that for $v << c$, the relativity of time is unremarkable, therefore in Galilean relativity there is no relative time. However, based on the physics presented in this paper, we learn that the opposite is true. In the case of speeds like those of a bicycle and wagon, time can be neglected in STR but not in Galilean relativity. Therefore, in this scenario, the TGT approach provides a different perspective compared to LT, emphasizing the importance of time in Galilean relativity even for small velocities. The results from the previous sections confirm that numerically.

The times t and t' in TGT and LT, also have different meanings. In TGT, these times hold significant and realistic interpretations in every event we consider, including everyday life scenarios such as the previously solved problem. The time t represents the time of the event itself, while the relative time t' corresponds to the time it takes for the cyclist to traverse the path x' (the road inside the wagon) at the relative velocity u. Relative time t' has a fundamental use in daily activities, and we commonly identify and measure events using this relative time alongside the time of the event t. When individuals calculate to "save time" by performing two simultaneous motions, they are essentially making calculations involving relative time. In TGT, relative time encompasses not only t', but also the other term in the second equation the system of Equation (24), which, when combined with t', yields the time of the event t. On the other hand, according to LT, the relative time t' obtained represents the time inside the wagon, and its rate of flow differs from the rate of flow of time t at the station. The difference between these two times (t and t') as explained by LT is referred to as time dilation. However, in everyday life, this difference is imperceptible and has no noticeable effect. In conclusion, the relative time in Galilean relativity, calculated using TGT, holds significance and cannot be disregarded. It remains evident even in everyday problems and can be measured using standard clocks. Conversely, in the context of STR and everyday problems, the relative time can be easily neglected.

7. CONCLUSIONS

This paper investigates the role of velocity magnitudes in compound relative motion and focuses on the impact of these velocities on the relativity of time. Comparing Galilean relativity to STR using concrete examples, the following conclusions are drawn. (i) The principle of relativity asserts the absence of privileged velocities. (ii) Consequently, the categorization of relativity theories based on velocity magnitudes is artificial and incorrect. (iii) The Lorentz transformation (LT) is initially derived for cases where the velocity of light is part of a compound relative motion. However, it is generalized and employed for all compound relative motions, even when the velocity of light is not involved. This generalization lacks a physical basis. (iv) Time is relative in Galilean relativity, and humans consistently calculate and consider this time in their daily events. The relativity of time in Galilean relativity necessitates the transformation of the current Galilean transformation to the transformed Galilean transformation. (v) The relativity of time can be neglected in STR, it cannot be neglected in Galilean relativity. In STR, the difference between times t and t' is of the order v^2/c^2, whereas in Galilean relativity, it is of the order v/u (where u represents a velocity of similar magnitude as v).

8. ACKNOWLEDGMENT

The authors would like to thank the University of Gjilan for funding this research through the regular Research Grant scheme.

REFERENCES

Alstein, P., K. Krijtenburg-Lewerissa, and W. R. van Joolingen (2021). Students' Preinstructional Reasoning with the Speed of Light in Relativistic Situations. *Physical Review Physics Education Research*, **17**(2); 023101

Anker, J. and F. Ziegler (2020). Relativity Without Light: A New Proof of Ignatowski's Theorem. *Journal of Geometry and Physics*; 103871

Berisha, V. and S. Klinaku (2017). The Only Pure Mathematical Error in the Special Theory of Relativity. *Physics Essays*, **30**(4)

Berisha, V. and S. Klinaku (2018). The Lorentz Factor and the Law of Cosines. *Physics Essays*, **31**(4)

Berisha, V. and S. Klinaku (2023). Invariance of the Acoustic Wave Equation Under Transformed Galilean Transformation. *Acoustical Science and Technology*, **44**(1)

Bhadra, A., A. Chakraborty, S. Ghose, and B. Raychaudhuri (2023). Synchronization Gauge Field, Standing Waves and One-Way-Speed of Light. *Physica Scripta*, **98**(12); 125024

Born, M. (2001). *Die Relativitaetstheorie Einsteins*. Springer, Berlin, 234 edition

Browne, K. M. (2020). Galilei Proposed the Principle of Relativity, But Not the Galilean Transformation. *American Journal of Physics*, **88**; 207

Einstein, A. and L. Infeld (1938). *Evolution of Physics*. The Scientific Book Club, London

Feynman, R. (1977). *The Feynman Lectures on Physics*, volume 1. California Institute of Technology, Pasadena

Griffiths, D. J. (2024). *Introduction to Electrodynamics*. Pearson Education, Inc., 5th edition

Günther, H. and V. Müller (2019). *The Special Theory of Relativity*. Springer Nature Singapore Pte Ltd.

Halliday, D., R. Resnick, and J. Walker (2022). *Fundamentals of Physics*. John Wiley & Sons, Inc., 12th edition

Ignatowski, W. (1910). Das Relativitätsprinzip. *Berliner Mathematische Gesellschaft und auf der 82. Naturforscher-Versammlung in Königsberg*

Kamphorst, F., M. J. Vollebregt, E. R. Savelsbergh, and W. R. van Joolingen (2019). Students' Preinstructional Reasoning with the Speed of Light in Relativistic Situations. *Physical Review Physics Education Research*, **15**(2); 020123

Klinaku, S. (2021). Galilean Transformation in Polar Coordinates and Doppler Effect. *Results in Physics*, **31**; 104885

Klinaku, S. (2022). Geometric Representation of the Galilean Transformation. *Results in Physics*, **39**; 105719

Klinaku, S. (2024). Galilean Relativity – Explained by Means of the Triangle Solutions. *Results in Physics*, **60**; 107631

Lämmerzahl, C. (2005). Special Relativity and Lorentz Invariance. *Annalen der Physik*, **14**(1-3); 71–102

Landau, L. D. and E. M. Lifshitz (1987). *The Classical Theory of Fields*, volume 2. Butterworth-Heinemann, 4th edition

Larmor, J. (1900). *Aether and Matter*. Cambridge University Press, Cambridge

Laue, M. (1911). *Die Relativitaetstheorie*. Friedr. Vieweg & Sohn

Nolting, W. (2017). *Theoretical Physics 4, Special Theory of Relativity*. Springer International Publishing, Switzerland

O'Donnell, P. J. (2015). *Essential Dynamics and Relativity*. CRC Press, Boca Raton, London, New York

Serway, R. and J. J. Jr. (2014). *Physics*. Brooks/Cole, 9th edition

Welters, A., Y. Avniel, and S. G. Johnson (2014). Speed-of-Light Limitations in Passive Linear Media. *Physical Review A*, **90**(2); 023847

